A combined earth-star sensor system and a method for determining the orbit and attitude of space vehicles

BACKGROUND OF THE INVENTION

The invention relates to a combined earth-star sensor system for three-axis attitude determination of satellites in space, as well as a method for determining the orbit and attitude of space vehicles.

For earth-oriented satellites, infrared sensors are presently used to determine roll and pitch angles, while solar sensors are used to determine the yaw angle of the satellite. This solution is associated with the disadvantage of the arrangement of several solar sensor heads used being very expensive, and of the lack of any yaw reference in the case of co-linearity of the earth and the sun. Furthermore, evaluation additionally requires an exact knowledge of the attitude of the satellite on its orbit. Moreover, errors between the measuring axes of solar sensors and earth sensors, e.g. caused by inaccuracies during installation or as a result of thermal influence, can significantly degrade the quality of measurements.

Known star sensors provide a three-axis attitude reference in an inertial system. Here too, earth alignment requires an exact knowledge of the satellite attitude. At present, CCDs are used for such star sensors. Due to their lack of radiation resistance, they are not suitable for use in orbits with substantial radiation load, e.g. for use in geosynchronous missions.

From EP 0 589 387 A1 a combined earth-star sensor system is known which uses a single optical arrangement to carry out both star observation and earth observation in the UV range. To carry out common

Substitute page 2, between paragraphs 2 and 3 insert the following heading:

observation, the optical arrangement comprises a wide-angle system incorporating a mirror system. Due to the coinciding directions of observation for earth observation and star observation, the known system is only able to observe stars in proximity to the earth; and due to the sensor being designed with the strong earth radiation in mind, for attitude determination the known system is only able to observe stars of high intensity.

From US 5,189,295 a combined earth-star sensor system for three-axis attitude determination in space is known, with the combined earth-star sensor system comprising separate apertures with different directions of observation and common image pickup devices for the earth sensor and the star sensor. The earth is partially shielded by a screen, so as to allow acquisition of the pole star. There is however a problem that the difference in brightness between the earth and stars has not been taken into account adequately. Consequently, adequate acquisition of the earth and stars is not ensured.

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SUMMARY OF THE INVENTION

It is thus the object of the invention to provide a combined earth-star sensor system which is not limited in regard to the selection of stars suitable for observation, and which can be produced economically and which allows optimal acquisition of the stars to be observed and the earth. Furthermore, it is the object of the invention to provide a method for determining the orbit and attitude of a space vehicle, said method being more accurate and allowing optimal acquisition of the stars to be observed and the earth, as well as allowing independent on-board operation.

Substitute page 3 delete the first paragraph:

The combined earth-star sensor system according to the invention, for three-axis attitude determination of satellites in space comprises separate apertures with different directions of observation and common image pickup devices for the earth sensor and the star sensor. The sensor allows variable control of the exposure time so that integration can be adapted to the difference in brightness of the stars and the earth. Preferably, exposure is always in turn, one frame long and one frame short.

Observation according to the invention, of the earth and the stars with different apertures makes it possible to observe stars of magnitude 5 too. The considerable difference in the intensity of radiation of these stars when compared to earth radiation, can be absorbed by different aperture design and filtering. In spite of concurrent observation of the earth, the detection of the stars is not influenced by the scattered light from the earth, if two apertures are used. The simple design of the system according to the invention can cope with high light intensities while keeping costs low. High light intensity allows the use of economical CMOS image pickup devices.

Preferably the CMOS image pickup devices form a CMOS focal plane array as a focal plane sensor with a dynamic range of up to $1:10^6$. It makes possible variable control of the exposure time, so that

Substitute page 5, between paragraphs 2 and 3 insert the following heading:

By filtering out or acquiring a long-wave fraction of the radiation, e.g. by means of edge filters, the rim of the earth can be acquired particularly well and with particularly good stability. Additional degrees of freedom can be determined by model-based tracking of the rim of the earth.

Further advantages of the invention include a lower mass or possible redundancy because there is no need for further equipment such as for example gyros which were hitherto required for determining the orbit and the attitude. This results in simplified integration and inherent radiation resistance. Orbit determination is possible without the use of GPS, in particular also for near-earth and geostationary satellites. In this way, independent on-board operation can be achieved.

B3 BRIEF DESCRIPTION OF THE FIGURES OF THE DRAWING

Below, embodiments of the invention are explained in more detail by means of the drawing.

Original page 5, between paragraphs 4 and 5 insert the heading:

Figure 1 shows a combined earth-star sensor system with a common optical arrangement;

Figure 2 shows a combined earth-star sensor system with two optical arrangements;

Figure 3 shows an arrangement of image pickup devices; and

Figure 4 shows a coordinate system whose Z-axis is directed towards the centre of the earth and whose X-axis points in the direction of orbit movement.

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DETAILED DESCRIPTION

The combined earth-star sensor system 1 shown in Figure 1 comprises a common optical arrangement 2, a deflection mirror 3, image pickup devices 4 and windows 6 and 7 for earth and star observation.

The system shown is in particular characterised in that the observation direction to the earth differs from the observation direction to the stars.

Starlight enters the window 6, passes the little deflection mirror 3, reaches the common optical arrangement 2 and is focussed onto the image pickup device 4. The light from the earth enters through the window 7, impinges on the deflection mirror 3 which directs it to the common optical arrangement 2. The common optical arrangement 2 focuses the light from the earth on the image pickup devices 4. In relation to a common optical arrangement 2, the image pickup devices 4 are arranged on a common focal plane according to a specified pattern. Figure 3 provides an example of a possible arrangement of four image pickup devices which provide coverage over a large field of vision at a